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POLLUTION EMISSION ANALYSIS OF SELECTED AIR FORCE AIRCRAFT

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The interest in pollution emissions from aircraft has been enhanced by EPA's recent determination that major civilian airports are significant contributors to localized air quality degradation. This report summarizes the USAF aircraft and engines in common use, presents normalized engine pollution emission factors (emission indices), suggests military landing and takeoff cycle times by aircraft type, and compares aircraft emission inventories for several Air Force bases.

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INTRODUCTION

Emission standards for control of pollution from civilian aircraft, as promulgated by EPA, have intensified the need for an accurate evaluation of the military's contribution to degradation of ambient air quality. While few people intuitively feel that airbases have as great an impact on the local environment as large civilian airports, the fact remains that the Air Force has some bases which rank among the largest civilian airports in flying activity. Since it would be incongruous to force stiff emission controls on civilian airlines yet not control or even analyze the impact of DOD aircraft, several related Air Force projects have been initiated.

By working closely with EPA, personnel from the Air Force Aero Propulsion Laboratory (AFAPL) developed pollution emission factors goals proposed for future Air Force aircraft engines (1).[1] The term "goals" is used since they are proposed to be used as design criteria by engine manufacturers but will not be issued as procurement regulations. Maximum allowable idle combustion inefficiencies of 1 percent are proposed in order to limit carbon monoxide (CO) and unburned hydrocarbons (UHC) emissions. Nitrogen oxide (NO_x) reductions of 50 percent (75 percent for large non-combat transport engines) are proposed. Smoke numbers which will ensure invisible aircraft smoke plumes are specified.

The AFAPL established military engine emission reduction goals designed to reduce pollution emission levels prior to the establishment of federal regulations to force such reductions. In this manner, regulations which produce effective pollution reductions, yet do not produce unacceptable cost of performance penalties, will hopefully be developed. However, the environmental effectiveness of the proposed goals or even the necessity of such goals on all USAF aircraft has not been fully developed. Data presented in this report is intended to provide background information for these needed environmental assessments.

SUMMARY OF RELATED LEGISLATION

The federal government has initiated laws for the specific purpose of preventing further degradation of the atmosphere. The Clean Air Act of 1963 (2) is the first major legislation to be enacted for the purpose of investigating and controlling air pollution, mainly at the regional and local level. The act gives the federal government authority to intervene in interstate problem areas.

The first mention of aircraft emissions as a possible source of air pollution in a federal law came about under Section 2116 of the Emission Standards Act of 1967 (3):

> "The Secretary shall conduct a full and complete investigation and study of the feasibility and practicability of controlling emission from jet and piston aircraft engines and of establishing national emission standards with respect thereto..."

This statement concerning the establishment of national emission standards for aircraft engines is the primary reason that considerable public interest has been generated in the area of aircraft emissions determination.

The Clean Air Act of 1970 which created the Environmental Protection Agency contains additional specific references to possible pollution being emitted from aircraft operations. The Clean Air Act contains in Section 231.1 the following statement:

> "The Administrator shall commence a study and investigation of emissions of air pollutants from aircraft in order to determine:
>
> A. The extent to which such emissions affect air quality in air quality regions throughout the 'nited States and,

[1] Underlined numbers in parenthesis designate References at end of paper.

B. The technological feasibility of controlling such emission."

Based on the information obtained from this study the Administrator (EPA) was to issue proposed emission standards applicable to the emission of any air pollutant from any class or classes of aircraft or aircraft engines.

The Clean Air Act of 1970 also contains Section 118 that directs all federal facilities to:

"...comply with federal, state, interstate, and local requirements respecting control and abatement of air pollution to the same extent that any person is subject to such requirements."

This section does allow the President to exempt any federal emission source if he determines that it is in the best interest of the country to do so.

The proposed standards for aircraft and aircraft engines were published in the Federal Register (4) on Tuesday, December 12, 1972 at the same time proposed standards for ground operation of aircraft to control emissions were published (5). Three major reasons for proposing these standards are stated as follows:

"...(1) that the public health and welfare is endangered in several air quality control regions by violation of one or more of the national ambient air quality standards,

...(2) that airports and aircraft are now, or are projected to be, significant sources of emissions or carbon monoxide, hydrocarbons and nitrogen oxides in some of the air quality control regions in which the national ambient air quality standards are being violated, as well as being significant sources of smoke,

...(3) that maintenance of the national ambient air quality standards and reduced impact of smoke emission requires that aircraft and aircraft engines be subjected to a program of control compatible with their significance as pollution sources."

The first of the proposed standards, "Control of Air Pollution from Aircraft and Aircraft Engines," was promulgated on July 17, 1973 (6). Emission standards are set for total hydrocarbons, carbon monoxide, oxides of nitrogen, and smoke. Standards apply to newly manufactured engines and in some cases, in-use engines. Test procedures are also indicated. These standards, however, do not currently apply to military aircraft.

The second of the proposed standards, entitled "Ground Operation of Aircraft to Control Emission," deals mainly with suggesting ways of modifying ground operations so as to reduce emissions for aircraft when they are on the ground during idle and taxi modes. Promulgation of these standards is being delayed to allow these modifications to be investigated more fully by EPA and the Department of Transportation since they could possibly lead to unsafe operating conditions.

The President issued Executive Order 11507 (7), February 4, 1970, "Control of Air and Water Pollution" with the following statement:

"The Order I am issuing today will require that all projects or installations owned by or leased to the federal government be designed, operated, and maintained so as to conform with air and water quality standards present and future — which are established under federal legislation."

The first section of the Executive Order, the policy statement, intends to broaden the responsibility of the federal government from maintaining its own facility to providing leadership to the nation in the areas of air and water pollution control and abatement. This task should be met and accomplished irrespective of the speed of compliance in the civilian sectors.

The Air Force has, therefore, initiated programs for both the impact analysis and the reduction of emissions from aircraft operations.

USAF AIRCRAFT AND ENGINES IN COMMON USE

To assist in any emissions analysis of USAF aircraft, a listing of aircraft types, engine types, engine manufacturers, number of engines per aircraft, and afterburner usage is presented in Table 1. The number of assigned active aircraft as of March 1972 is also given to show comparative aircraft strengths. They should be used only as relative values since the actual number of active aircraft is constantly changing. Engine prefixes are TF or F for turbofan engine designs, J for turbojets, T for turboprop engines (including helicopters) and R, O, or IO for piston engines.

Engine flying hours are, perhaps, a better indicator of emissions than assigned aircraft. A percentage breakdown of each is given in Table 2. While engine flying hours are a good indicator

Table 1 USAF Aircraft Included in Assessement Program

AIRCRAFT	NUMBER AIRCRAFT*	ENGINE TYPE**	ENGINES FOR AIRCRAFT	AFTERBURNER
Bombers				
B-1	N/A	F-101 (GE)	4	Yes
B-52 C-E	268	J-57-19W (P)	8	No
F-G	247	J-57-43WB (P)	8	No
H	99	TF-33-3 (P)	8	No
B-57A-3C	60	J-65 (W)	2	No
E-G	67	TF-33-11 (P)	2	No
Subtotal = 7	= 741			
Fighters				
F-100A-F	716	J-57-21 (P)	1	Yes
F-101 A-H	2	J-57 55 (P)	2	Yes
F-102A	118	J-57-23 (P)	1	Yes
F-104A-G	149	J-79-38 (GE)	1	Yes
F-105B-G	259	J-75-19W (P)	1	Yes
F-106A-B	259	J-75-17 (P)	1	Yes
F-4A-D	1265	J-79-15 (GE)	2	Yes
E	634	J-79-17 (GE)	2	Yes
F-5A-B	24	J-85-13 (GE)	2	Yes
F-111A-F	304	TF-30-9 (P)	2	Yes
F-15	N/A	F-100 (P)	2	Yes
Subtotal = 11	= 4368			
Attack Aircraft				
A-7D	195	TF-41-A-1 (A)	1	No
A-10	N/A	TF-34-2(GE)	2	No
A-37A	24	J69-25 (Cont)	2	No
B	202	J-85-17A (GE)	2	No
Subtotal = 4	= 421			
Cargo Aircraft				
C-5A	53	TF-39 (GE)	4	No
C-9A	14	JT-8D-9 (P)	2	No
C-130A-S	715	T56-7 (A)	4	No
KC-135A	619	J-57-59W (P)	4	No
B-U	143	TF33-5 (P)	4	No
C-141A	281	TF-33-7 (P)	4	No
C-7	116	R2000	2	No
C-47A-Q	198	R-1830-SIC3-G (P)	2	No
C-97D-L	143	R-4360 (P)	4	No
C-119 G/K	125	R-3350-89BW/J-85	2/4 (plus 2 J-85's in "K" model only)	No
Subtotal = 9	= 2407			
Training Aircraft				
T-29	333	R-2800-99 (P)		NO
T-33A-B	882	J33-35 (A)	1	No
T 37B	812	J69-T25 (C)	2	No
T-38	1053	J85-5 (GE)	2	Yes
T-39A-F	141	J60 3A (P)	2	No
T-41A-C	240	O-300(C)	1	NO
Subtotal = 8	= 3461			
Observation Aircraft				
O 1A		O470 (C)	1	No
O 2A,B	394	IO360D (C)	2	No
OV-10A	110	T-76	2	No
Subtotal = 3	= 818			
Helicopters				
HH-3	94	T58-5 (GE)	1	No
HH-43B-F	149	T53-1 (L)	1	No
HH-53BC	57	T64-7 (GE)	2	No
UH-1F	69	T58-3 (GE)	1	No
N,N,P	127	T53-13 (L)	1	No
Subtotal = 5	= 496			
TOTALS				
48 Aircraft types	12,410 Aircraft	8 Turbojets 8 Turbofans 5 Turboprops 8 Pistons		7 Afterburning Engines
		29 Basic Engine Models		

* The number of aircraft per model was compiled from the AFLC prepared Aerospace Vehicle Inventory report dated 21 March 1972 which was declassified on 21 March 1973.

** Engine Manufacturers Code: GE - General Electric; P - Pratt & Whitney Aircraft; A - Allison; C - Continental; G - Garrett Air Research; L - Lycoming.

of relative nationwide emissions, caution must be taken if trying to apply this data to a local airbase emissions analysis. Some engines, such as the TF-39, may be only in the 1 percent category of all flying activity, but can still be of major consideration at particular airbases. The only suitable way of doing emissions analysis for local airbases is to use aircraft flight information specific to the area. Unlike large civilian airports which have a relatively homogeneous mix of passenger/cargo aircraft, Air Force bases have vastly dissimilar aircraft operations depending on the tactical, strategic, training, or logistics mission of the particular airbase.

ENGINE EMISSION FACTORS

Numerous efforts to measure aircraft engine emissions have been initiated over the past six years. Nevertheless, the data base for engine emission factors is still inadequate, particularly for military aircraft. Current Air Force efforts to measure engine emissions are underway at the USAF Aero Propulsion Laboratory, the Air Force Weapons Laboratory, and the Arnold Engineering and Development Center. Two major measurement problems are still unsolved: (a) how to measure particulates in such a way as to include only those condensables which actually condense in the atmosphere, and (b) how to quantify pollutants from afterburning engine modes which are hot enough to be reactive for up to 15 duct diameters downstream from the engine exhaust.

In addition to the technical problems, many logistical problems exist which make obtaining realistic engine emission factors difficult to obtain. These problems and a literature review showing great scatter in emission data were the subject of a previous report (8). Only the composite emission factors are printed here as Table 3. While many of these values are not supported by a strong statistical data base, they are hopefully the most accurate emission factors based on present data. These values should satisfy the immediate need for preliminary emission factors to be used in Environmental Impact Assessments and Statements. The emission factors presented in this table are a composite of published data or, in some cases, represent the only measurement presently available for the specific engine series. The footnotes that accompany each emission factor provide the reference or references that were used in determining the composite value and the method used in determining the numerical value.

Emission factors in Table 3 represent the emissions from about 43 percent of all engine models currently in use by the Air Force but account for about 82 percent of the total engine usage. Relating these engines to associated aircraft can be done with the use of Table 1. A comparison of both tables will indicate the degree of unavailability of emission factors. For example, of the 21 turbine engine models presented in Table 1, only 10 are presented in the composite Table 3 as having emission factors available.

Table 2 USAF Aircraft Engine Usage

Engine	Percentage of Major Engines	Percentage of Flying Hours
J-57	30.1	26.3
TF-33	9.3	17.8
T-56	11.2	15.8
J-85	10.5	10.5
J-79	15.6	9.5
J-69	6.6	7.2
J-60	1.4	2.5
T-76	.9	1.6
TF-30	2.8	1.5
J-33	2.2	1.5
TF-39	.9	1.1
J-75	2.0	1.0
T-58	1.4	1.0
TF-41	1.7	.8
J-65	1.1	.5
T-64	.5	.4
T-53	.6	.3
T-400	.5	.3
J-71	.4	.3
J-47	.3	.1

* Based on data from AFLC/WPAFB for 19,036 installed active engines for the first quarter of 1972.

LANDING AND TAKEOFF CYCLES

Obtaining an accurate characterization of aircraft operational procedures is equally as important as obtaining accurate engine emission indices when performing an overall emissions analysis. Operational information includes the total number of takeoffs and landings for a given aircraft model and an accurate description of average aircraft landing and takeoff (LTO) cycles. A nine-category aircraft LTO cycle is being used

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Table 3 Composite A/C Engine Emission Factors

Engine: Military	Engine: Civilian	Mode	Fuel Rate Average (1000 lb/hr)	Particulates	Nitrogen Oxides	Carbon Monoxide	Unburned Hydrocarbons
				Pollutant Emission Rate (lbs/1000 lb of fuel)			
J-79		IDLE	1.068 [1]	32.4 [3]	3.69 [4]	59.8 [4]	6.18 [4]
		NORMAL-Cruise	8.33 [2]		7.96 [5]	2.25 [5]	0.03 [5]
		MILITARY	8.47 [1]	12.8 [3]	11.39 [4]	1.9 [4]	0.5 [4]
		AFTERBURNER	30.55 [1]	7.18 [6]	5.08 [6]	31.9 [6]	0.4 [6]
J-57		IDLE	1.17 [7]	8.3 [8]	2.02 [9]	88.0 [9]	85.0 [9]
		NORMAL-Cruise	7.28 [7]		9.26 [9]	1.96 [9]	.84 [9]
		MILITARY	8.68 [7]	12.0 [8]	10.50 [9]	1.28 [9]	.22 [9]
J-52		IDLE	0.71 [10]	7.3 [11]	6.74 [10]	66.9 [10]	21.85 [10]
		NORMAL-Cruise	5.34 [10]	49.0 [11]	10.0 [10]	1.99 [10]	.08 [10]
		MILITARY	6.56 [10]	22.0 [11]	9.36 [10]	1.73 [10]	.87 [10]
TF-33		IDLE	1.18 [12]	8.0 [13]	1.65 [14]	116.7 [14]	107.6 [14]
		NORMAL-Cruise	7.32 [12]	14.0 [13]	11.26 [14]	1.54 [14]	.37 [14]
		MILITARY	8.60 [12]	14.0 [13]	13.63 [14]	.71 [14]	.27 [14]
TF-30		IDLE	1.25 [1]	26.5 [3]	1.51 [16]	72.9 [16]	17.72 [16]
		NORMAL-Cruise	6.65 [15]		12.16 [16]	1.20 [16]	0.08 [16]
		MILITARY	7.12 [1]	23.7 [3]	13.79 [16]	1.37 [16]	0.10 [16]
		AFTERBURNER	42.85 [1]	5.36 [3]	4.47 [6]	24.8 [6]	0.1 [6]

Footnotes:

1. Data from Gurnett, R. D.. Noise and Pollution Emissions from Noise Supressors for Engine Test Stands and Aircraft Power Check Pads. Flow Rates are averaged. Report 71M-19 January, 1972 USAF Environmental Health Laboratory.
2. Bogdan, Leonard and McAdams, H. T.: Analysis of Exhaust Emission Measurements. CAL Report No. NA-5007-K-1: October, 1971. Averages by similar fuel flow rates at 80-90° T.O. Power.
3. Data from (1). This includes organic soluble and insoluble particulates.
4. Average of raw data from (1 & 2). For J-79.
5. Average of raw data from (2). For J-79.
6. Data for one engine test obtained from (1).
7. P&WA specification A-1730 February, 1958 Guaranteed Rating.
8. Data from Nature and Control of Aircraft Engine Exhaust Emissions: Northern Research and Engineering Corporation Report No. 1134-1. Eng. A - JT3C. Data does not specify whether soluble particulates are included or not.
9. Average of one set of data on the J-57 from (2) and two sets of average data from H. T. McAdams: Analysis of Exhaust Emission Measurements: Statistics CAL Report No. NA-5007-K-2; November, 1971 - for the JT3C.
10. Average of raw data from (2) for J-52.
11. Data from Contract Status Report No. 3. Fred Robson, United Aircraft Research Laboratories; Original Data Source: measurements by Environment-One as reported in Report on Abatement of Particulate Emissions and Noise from Jet Engine Test Cells Including Reduction of Gas Flow with TESI Augmentor-Scrubber System. Teller Environmental Systems, Inc.
12. P&WA Specification A-1758G March, 1962 Guaranteed Rating.
13. Data from (11) does not specify if soluble particulates are included.
14. Average of 4 data sets from (2), JT3D, and 1 set of data from (11).
15. P&WA Specification A-6123-A September, 1970 Guaranteed Rating.
16. Average of 12 sets of raw data from (2) for TF-30.

Table 3 (Continued)

Engine: Military	Engine: Civilian	Mode	Fuel Rate Average (1000 lb/hr)	Pollutant Emission Rate (lbs/1000 lb of fuel): Particulates	Nitrogen Oxides	Carbon Monoxide	Unburned Hydrocarbons
J-85		IDLE	.65 [1]		5.3 [1]	150.0 [1]	42.0 [1]
		NORMAL-Cruise	1.8 [1]		3.6 [1]	58.0 [1]	9.4 [1]
		MILITARY	2.66 [1]		5.4 [1]	46.0 [1]	5.8 [1]
		AFTERBURNER	7.70 [1]		3.1 [1]	35.0 [1]	4.0 [1]
J-75		IDLE	1.7 [2]	.5 [3]	1.29 [2]	76.2 [2]	56.86 [2]
		NORMAL-Cruise	11.3 [2]		11.9 [2]	1.4 [2]	.1 [2]
		MILITARY	13.2 [2]	1.05 [3]	8.2 [2]	.6 [2]	.23 [2]
		AFTERBURNER	53.7 [2]				
TF-30		IDLE	1.198 [2]		5.36 [2]	50.0 [2]	17.0 [2]
		NORMAL-Cruise	12.42 [2]				
		MILITARY	12.86 [2]		42.8 [2]	3.0 [2]	.3 [2]
T-56		IDLE	.548 [4]		3.93 [4]	28.10 [4]	11.92 [4]
		NORMAL-Cruise	1.988 [4]		11.11 [4]	1.57 [4]	.25 [4]
		MILITARY	2.879 [4]		10.98 [4]	1.04 [4]	.20 [4]
T-76		IDLE	.192 [5]		7.35 [5]	23.78 [5]	7.42 [5]
		NORMAL-Cruise	.347 [5]		9.88 [5]	5.92 [5]	.11 [5]
		MILITARY	.387 [5]		10.27 [5]	2.28 [5]	.084 [5]
O-470 R		IDLE	.01512 [6]		1.02 [6]	742.5 [6]	191.4 [6]
		NORMAL-Cruise	.0866 [6]		9.37 [6]	691.66 [6]	9.46 [6]
		MILITARY	.13125 [6]		1.11 [6]	1155.8 [6]	20.40 [6]
IO-360		IDLE	.01517 [7]		1.09 [7]	848.18 [7]	144.58 [7]
		NORMAL-Cruise	.06788 [7]		6.68 [7]	971.97 [7]	17.40 [7]
		MILITARY	.0887 [7]		5.32 [7]	1031.25 [7]	22.47 [7]

Footnotes:

[1] Lazalier, G. R. and Gearhart, J. W.: Measurement of Pollutant Emissions From an Afterburning Turbojet Engine at Ground Level.

[2] Robson, F. L., Kesten, A. S. and Lessard, R. D.: Analysis of Jet Engine Test Cell Pollution Abatement Methods. AFWL-TR-73-18.

[3] Average of data from reference 2.

[4] Bogdan, Leonard and McAdams, H. T.: Analysis of Exhaust Emission Measurements. CAL Report No. NA-5007-K-1: October 15, 1971.

[5] Engineering Staff: "Exhaust Emissions Test AiResearch Aircraft Propulsion and Auxiliary Power Gas Turbine Engines", AiResearch Manufacturing Company of Arizona.

[6] Bogdan, Leonard and McAdams, H. T.: Analysis of Exhaust Emission Measurements. CAL Report No. NA-5007-K-1: October 15, 1971. Page II-35.

[7] Bogdan, Leonard and McAdams, H. T.: Analysis of Exhaust Emission Measurements. CAL Report No. NA-5007-K-1: October 15, 1971. Page I-108.

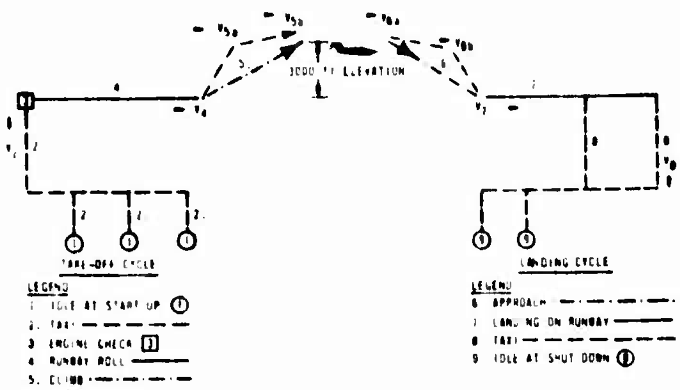

Fig. 1 Landing and Take-off Cycles

as illustrated in Fig. 1. An example data sheet is presented in Table 4. Climb-out and approach are given two steps in military aircraft to account for afterburner shut-off or other engine mode changes. Climb and approach modes are defined as being only below a 3000-ft actual ground level which is in agreement with EPA studies.

Two additional categories are usually used to completely describe all emissions. Category 10 describes aircraft "touch and go" operations which are used as training methods at many Air Force bases. Operations will generally include the same aircraft modes as Category 6 (approach from 3000 ft); a short runway roll of approximately 0.1 times Category 4, and a climb-out as described in Category 5. Annual emissions from touch-and-go operations can be nearly as great as from landings and takeoffs at some airbases.

A final category describes the amount of raw fuel which is spilled, dumped, or vented in an average LTO cycle. This value will vary considerably by aircraft type and by operating procedures.

Examples of LTO cycle times are given in Table 5. On each of the nine aircraft categories described in the foregoing, an average time per operation is presented. Some of the times, such as taxi duration before takeoff, are more a function of airbase design and operation than of aircraft type. Other times such as the duration of climbout to 3000 ft are almost exclusively a function of aircraft type and meterorological conditions. Average times for each LTO category may, therefore, be tailored to suit local conditions. The specific times shown were obtained from questionnaires and personal interviews with instructor pilots. Cycle times have also been spot-checked during actual fighter and training aircraft operations.

The EPA LTO cycle times are also shown in

Table 4 Landing and Takeoff Sample Data Sheet

AIRCRAFT TYPE ____________

COMMAND/BASE ____________

AIRCRAFT MODE	ENGINE MODE (LBS FUEL/HR)	TIME* (SEC)	DISTANCE** (FT)	SPEED*** (FT/SEC)	ADDITIONAL DATA
1. IDLE AT START UP					
2. TAXI BEFORE TAKE-OFF					
3. ENGINE CHECK AT RUNWAY END					
4. RUNWAY ROLL					AVG TAKE-OFF WEIGHT____
5a. CLIMBOUT-STEP #1					STEP #1 HEIGHT____ AVG CLIMB ANGLE____
b. CLIMBOUT TO 3000' AGL-STEP #2					AVG CLIMB ANGLE____
6a. APPROACH FROM 3000' AGL-STEP #1					AVG DECENT ANGLE____
b. APPROACH FROM-STEP #2					STEP #2 HEIGHT____ AVG DECENT ANGLE____
7. LANDING ON RUNWAY					DRAG CHUTE: YES __ NO __ % OF TIME USED____
8. TAXI AFTER LANDING					
9. IDLE AT SHUTDOWN					
10. TOUCH & GO OPERATIONS			(ON RUNWAY)		

11. AMOUNT OF FUEL LOST (SPILLED, VENTED, PURGED) DURING FOLLOWING OPERATION
A. REFUELING ________ C. TAXI ________ E. ENGINE SHUT-DOWN ________
B. ENGINE START-UP ________ D. TAKE-OFF ________ F. OTHER ________

* WHERE POSSIBLE, CALCULATE: TIME = DISTANCE ÷ AVG SPEED

** DISTANCE HORIZONTAL COMPONENT ONLY

*** SPEED AS INDICATED IN ATTACHED FIGURE: $\bar{V}$=AVG SPEED, V=INSTANTANEOUS SPEED

Table 5 Landing and Takeoff Cycle Times (MINUTES)

AIRCRAFT MODE	F-4	F-104	T-37	T-38	B-52	KC-135	EPA MILITARY TRANSPORT	EPA MILITARY JET
1. IDLE AT START UP	10	5	4	5	20	20	19	6.5
2. TAXI BEFORE TAKE-OFF	15	14	8	6	9	9.5		
3. ENGINE CHECK AT RUNWAY END	0.5	0.8	0.5	0.3	4.5	2.5		
4. RUNWAY ROLL	0.3	0.4	0.4	0.4	0.6	0.9	0.5	0.4
5a. CLIMBOUT-STEP #1	0.4	0.6	1.2	0.2	0.7	0.7	2.5	0.5
5b. CLIMBOUT TO 3000 ft AGL-STEP #2	0.3	0.3	–	0.7	0.8	1.0		
6a. APPROACH FROM 3000 ft AGL-STEP #1	1.9	1.7	3.4	2.1	3.3	3.5	4.5	1.6
6b. APPROACH-STEP #2	0.7	0.4	0.8	0.3	1.0	1.1		
7. LANDING ON RUNWAY	1.0	1.0	1.4	1.0	1.0	10	7.0	6.5
8. TAXI AFTER LANDING	12	12	4.0	9.0	10	10		
9. IDLE AT SHUTDOWN	0.5	1.7	0.8	0.3	8	8		
TOTAL	42.6	37.9	24.5	25.3	58.9	58.2	33.5	15.5

Table 6 Emissions Per LTO Cycle (POUNDS PER CYCLE)

EMISSION TYPE	MILITARY AIRCRAFT						COMMERCIAL AIRCRAFT*	
	F-4	F-104	T-37	T-38	B-52H	KC-135A	707	727 (SMOKELESS)
CO	114	56	7 5	9 5	7 4 4	259	133	46
THC	9.8	4 4	19	2 5	680	198	74	7
NO_x	14	7 3	3 7	4 3	170	61	30	31
TOTAL PARTICULATES**	62	29	17	20	220	87	–	–
SO_x	1 1	56	31	37	7 4	3 4	–	–

*CALCULATED FROM CORNELL AERO LAB. REPORT NA-5007-K-1

**A PARTICULATE MEASUREMENT TECHNIQUE HAS NOT YET BEEN STANDARDIZED. THESE VALUES INCLUDE ALL CONDENSABLE PARTICULATES AND ARE FAR HIGHER THAN SOLID PARTICULATES ALONE.

Table 7 Emissions Per Touch-and-Go Cycle (POUNDS PER CYCLE)

EMISSION TYPE	MILITARY AIRCRAFT					
	F-4	F-104	T-37	T-38	B-52H	KC-135A
CO	15.4	10.5	36	30	9	8
THC	.22	.15	5.8	4.6	6	6
NO_x	5	3	2.8	2.4	52	25
TOTAL PARTICULATES**	9.8	5	9.9	7.8	56	29
SO_x	.32	.19	.25	.23	1.6	1.0

*CALCULATED FROM CORNELL AERO. LAB. REPORT NA-5007-K-1

**A PARTICULATE MEASUREMENT TECHNIQUE HAS NOT YET BEEN STANDARDIZED. THESE VALUES INCLUDE ALL CONDENSABLE PARTICULATES AND ARE FAR HIGHER THAN SOLID PARTICULATES ALONE.

Table 5 for "military transport" and "military jet" categories. Significant differences exist between the generalized EPA times and those presented here. These differences could cause emissions to be underpredicted by as much as 60 percent if using the generalized cycle times. Many factors could explain the cycle time differences. For example, F-4 and F-104 aircraft might spend large idle times after start of taxi if they have ordinance which must be armed at the end of the taxiway prior to takeoff and de-armed after landing. T-38 aircraft can have additional taxi after landing times at very active training bases where crossing runways is required to get to the parking ramp areas. B-52 and KC-135 aircraft often have long ground idle times in preparation for lengthy missions.

EMISSIONS FROM SELECTED AIRCRAFT

Emission factors and aircraft operating procedures were combined to calculate the total emissions per cycle for selected aircraft. Calculations were accomplished by using the Source Inventory computer code which is part of the USAF Air Quality Assessment Model (AQAM) (9). This code uses grid coordinates of parking ramps, taxiways, and runways, along with either LTO cycle times or actual aircraft velocities to compute the emissions. Takeoff lengths are adjusted to actual aircraft gross weights, ambient temperatures, pressure altitudes, and wind conditions. While this degree of complexity is not required for most emissions analysis, it is desirable for accurate dispersion analysis which is also a function of the AQAM.

Emissions per LTO cycle for selected aircraft are presented in Table 6. Afterburning (A/B) modes during takeoff and initial climb-out are assumed for the F-4, F-104, and T-38 aircraft. Total particulate emissions are computed to enable rough comparisons between aircraft types. However, caution must be used when determining the environmental significance of these particulates. A large portion of these "particulates" are condensables occurring in the sampling train but which might remain in the vapor state if diluted by the atmosphere during normal aircraft operation.

Emissions per "Touch and Go" cycle are presented in Table 7. Touch and Go training operations are important since they can be over three times more numerous than complete LTO cycles at some Air Force bases. A Touch and Go (TC) cycle is assumed to include a full approach mode, 0.1 times the runway roll distance, and a full climb-out mode. The 0.1 times runway roll relationship was developed from observations at Air

Table 8 Annual Aircraft Emissions (TONS PER YEAR)

EMISSIONS*	LUKE AFB		WILLIAMS AFB		WRIGHT-PATTERSON AFB	
	F-4	F-104	T-37	T-38	B-52H	KC-135A
CO	1640	486	2628	4510	293	156
THC	135	37	561	1095	265	190
NOX_x	216	67	162	233	124	75
TOTAL PARTICULATES	900	251	651	991	148	95
SO_x	16.7	5.1	14	21	4.6	3.6
*ABOVE EMISSIONS BASED ON:						
LTO CYCLES PER YEAR	27,500	16,380	39,662	77,281	760	1,100
TG CYCLES PER YEAR	9,500	5,292	63,357	55,963	2,280	3,300

Force Tactical and Training bases. The entire TG cycle is quite variable and may need to be adjusted for a specific local area. For example, aircraft operations at some bases employ "low fly-over" maneuvers in which the aircraft never touches the runway.

A comparison of Tables 6 and 7 is useful in determining if most emissions are being caused by either "high power" or "low power" operating modes. For example, B-52 aircraft exhibit high carbon monoxide (CO) and total hydrocarbon emissions (TCH) during an LTO cycle but low emissions during a TG cycle. Emissions are, therefore, caused primarily by the "low power" start-up and taxi modes. Oxides of nitrogen (NO_x), however, are "high power" pollutants and are nearly as great in a TG cycle as the complete LTO cycle.

Comments concerning emissions by aircraft type are as follows:

F-4 and F-104

Both are fighter aircraft using the J-79 engine. F-4 emissions are understandably about double those of the F-104 for all pollutants since it has two engines. NO_x and particulate emissions are high compared with most other aircraft. Exhaust plumes are highly visible at rated thrust and slightly visible in the A/B mode.

T-37 and T-38

Both of these training aircraft are used extensively at undergraduate pilot training bases. Insufficient emission measurements are available on the T-69 engines used in the T-37. Therefore, the emissions shown have been extrapolated from J-85 engine data. Both the T-37 and T-38 aircraft show low NO_x emission, moderate CO emissions, and relatively high THC emissions.

KC-135A

Emissions shown are from the four turbojet engines on the "A" model aircraft which is used extensively as a refueling tanker aircraft. Later models use a turbofan design. High CO and THC emissions are shown and are almost exclusively from ground operations at lower power settings.

B-52H

This heavy bomber aircraft uses eight turbofan engines. Very high LTO cycle emissions of CO, THC, and NO_x are produced in comparison with commercial 707 and 727 aircraft. Despite the high emissions per aircraft operating cycle, B-52 aircraft often contribute smaller annual emissions than aircraft which are flown on shorter, more frequent missions.

Annual emissions are summarized for three Air Force bases in Table 8. The Air Training Command base (Williams AFB) with its small but very active training aircraft easily contributes higher annual CO and THC emissions than either the Tactical Air Command (Luke AFB) or the Strategic Air Command (Wright-Patterson AFB) bases

which have been considered. However, NO_x and total particulate emissions from the F-4 aircraft are as high as the T-38 aircraft annual emissions.

SUMMARY AND CONCLUSIONS

Even though federal emission control regulations presently exclude military aircraft, steps are being taken to analyze and control the impact of aircraft operations. Listings of active Air Force aircraft and associated engines are presented.

An outline for categorizing military aircraft into landing and takeoff cycle components is proposed. Cycle times for the six USAF aircraft studied are significantly longer than the standard EPA cycle times. Substantial error in impact assessments is, therefore, possible unless specific military aircraft operating procedures are considered. A comparison of emissions is given for both LTO cycles and touch-and-go cycles.

While the B-52 aircraft have significantly higher emissions per LTO cycle than commercial 707 and 727 aircraft, annual emissions are low due to low activity levels. The highest annual emissions at the three bases chosen were produced by the small but highly active training aircraft.

REFERENCES

1 Blazowski, W. S. and Henderson, R. F., Assessment of Pollution Measurement and Control Technology and Development of Pollution Reduction Goals for Military Aircraft Engines, AFAPL-TR-72-102, Nov. 1972.

2 Clean Air Act (42 U.S.X. 1857 et seq.) includes the Clean Air Act of 1963 (P.L. 88-206) and amendments made by the Motor Vehicle Air Pollution Control Act (P.L. 89-272) (Oct. 20, 1965), the Clean Air Act Amendments of 1966 (P.L. 89-675) (Oct. 15, 1966), the Air Quality Act of 1967 (P.L. 90-148) (Nov. 21, 1967), and the Clean Air Act Amendments of 1970 (P.L. 91-604) (Dec. 31, 1970).

3 Public Law 90-148, Title II National Emission Standards Act, Section 2116, Nov. 21, 1967.

4 Federal Register, Vol. 37, No. 239, Part 2, Dec. 12, 1972.

5 Federal Register, Vol. 37, No. 239, Part 3, Dec. 12, 1972.

6 "Control of Air Pollution From Aircraft and Aircraft Engines," Federal Register, Vol. 38, No. 136, Part 2, July 17, 1973.

7 Executive Order 11507, Nixon, Richard M., Feb. 4, 1970.

8 Naugle, D. F. and Delaney, B. T., USAF Aircraft Pollution Emissions, AFWL-TR-73-199, Nov. 1973.

9 Wangen, Lawrence and Rote, D. M., A Generalized Air Quality Assement Model — A Users Manual, Argonne National Laboratory, AFWL-TR-74-56, March 1974.

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The interest in pollution emissions from aircraft has been enhanced by EPA's recent determination that major civilian airports are significant contributors to localized air quality degradation. This report summarizes the USAF aircraft and engines in common use, presents normalized engine pollution emission factors (emission indices), suggests military landing and takeoff cycle times by aircraft type, and compares aircraft emission inventories for several Air Force bases.

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